U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-260 208

REPORT OF COMMITTEE ON PERSISTENT PESTICIDES DIVISION OF BIOLOGY AND AGRICULTURE NATIONAL RESEARCH COUNCIL TO U.S. DEPARTMENT OF AGRICULTURE

NATIONAL RESEARCH COUNCIL, WASHINGTON, D.C.

PREPARED FOR
DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

MAY 1969

EPA/540/9 69/003

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No. PB-260 208
4. Title and Subtitle Report of Committee on Persistent Pesticides, Division of Biology and Agriculture, National Research Council to U. S. Department of Agriculture			5. Report Date May 69 6.
7. Author(s)			8. Performing Orgarization Rept. No.
9. Performing Organization Name and Address National Research Council, Washington, D. C. Committee on Persistent Pesticides			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address Deaprtment of Agriculture, Washington, D. C.			13. Type of Report & Period Covered 14.

15. Supplementary Notes Sponsored in part by Department of Agriculture, Washington, D. C.

16. Abstracts Environmental contamination resulting from the use of persistent pesticides in the continental United States is discussed. The report concludes that contamination of the biosphere by persistent pesticides is an internation problem and that changes in techniques for using such pesticides and the substitution of alternatives are questions of concern to all mankind. Included are seven recommendations by the committee.

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms
*Pesticide residues
Public health
Ecosystems
Air pollution sampling
Environmental effects

17c. COSATI Field/Group 13B

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 42
	20. Security Class (This Page UNCLASSIFIED	22. Price

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

300124

PB 260 208

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REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

May 1969

EPA - 540/9-69-003 (USDA)

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PREFACE

Release of chemicals into the environment must be evaluated continually in relation to human health, food production, welfare of the biota, and status of the environment. Some pesticidal chemicals persist long after they are applied, and they retain such toxicity that the advisability of their continued use has been challenged.

The Committee on Persistent Pesticides was established by the National Research Council (through the Division of Biology and Agriculture) to examine the subject of persistent pesticides. The Council's action was in response to a request made to Dr. Frederick Seitz, President, National Academy of Sciences-National Research Council, by Dr. George L. Mehren, formerly Assistant Secretary, U.S. Department of Agriculture.

In his request, made on November 29, 1966, Dr. Mehren referred to certain recommendations contained in a report on the use of pesticides that was issued by the President's Science Advisory Committee in 1963.

The report included a recommendation for "a monitoring program conducted by Federal Agencies to obtain timely, systematic data on pesticide residues in the environment." The report recommended that "the accretion of residues in the environment be controlled by orderly reduction in the use of persistent pesticides" and stated that "elimination of the use of persistent toxic pesticides should be the goal."

Pointing out that several agencies had undertaken monitoring studies to obtain information on residues, Dr. Mehren stated that it seemed appropriate to consider the most recent information on residues and to appraise the significance of residues from the standpoint of their effects on "the safety of our food supply and on the safety of man and our environment."

The Committee held its first meeting in December 1967. This was followed by a series of meetings in which the Committee heard representatives of government agencies, industrial and user groups, and conservation organizations. The assistance of those who provided information to the Committee is gratefully acknowledged. Without it, this review could not have been made. A list of the persons interviewed appears in the appendix.

The Committee believes that demonstrable progress has been made in further understanding some of the issues raised and in implementing some of the recommendations in the report by the President's Science Advisory Committee. However, it is concerned about what remains to be accomplished and about the many gaps in our knowledge of pesticides. It is convinced that there is an immediate need for world-wide attention to the problem of buildup of persistent pesticides in the total environment.

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INTRODUCTION

Man's primary concerns have always been the struggle for survival and improvement of his lot. As his numbers increased, he attained greater ability to manipulate his environment. In the process he sometimes inflicted damage on himself and on his surroundings. Advances have always entailed a degree of risk which society must weigh and either accept, or reject, as the price of material progress.

A major step in civilization was the domestication of food plants. With the birth of organized agriculture and the resultant concentration of crops and animals, the stage was set for outbreaks of pests. Until that time man had to search for food as did the pests. Afterward neither had to search; instead, pest control became necessary. The welfare of an increasing human population requires intensified agriculture. This in turn enables the pests to increase, which necessitates the use of pesticides with their concomitant hazards. It thus seems inevitable that, as the population increases, so do certain hazards.--President's Science Advisory Committee, Use of Pesticides, May 1963, p. 1

Most pesticide use involves release of chemicals into an ecosystem that includes living organisms and the nonliving substances associated with them. In such use, the intention is to restrict the chemicals to the treated areas. However, in spite of this intention, pesticidal chemicals often enter untreated areas of the biosphere.

Although much attention has been given to long-lived organochlorine insecticides, they are not the only persistent chemicals that cause concern. Inorganic pesticidal chemicals are also persistent; among these are chemicals containing lead, copper, arsenic, and mercury. Moreover, not all problem-causing organic chemicals in the environment are pesticides. Other organic compounds used or produced in

industry, and industrial waste products, leave persistent residues that add to the contamination in the biosphere.

The breakdown of a pesticidal chemical alters the parent molecule, and the alteration often results in a less toxic product. Some pesticidal chemicals break down and disappear soon after application. Others degrade or dissipate slowly, and their residues remain in decreasing but measurable concentrations for varying periods of time; it is to these that the relative term "persistent" is applied. Some persistent pesticidal chemicals remain in the environment for months or years, the rate of degradation varying with the local environmental conditions. Some of the organochlorine insecticides and certain other persistent pesticides are disseminated by natural forces throughout the biosphere, and they have characteristics that favor accumulation and storage by organisms. Much of the present public concern is directed to pesticides having these characteristics.

This report discusses environmental contamination resulting from the use of persistent pesticides in the continental United States. However, the Committee is well aware that, because of the mobility of some persistent chemicals in the atmosphere and in water, contamination of the biosphere must be viewed as a global problem.

NEED FOR PESTICIDES

During the past quarter of a century, nations in all parts of the world have benefited from increasing use of the synthetic organic pesticidal chemicals. Through use of these chemicals, spectacular control of diseases caused by insect-borne pathogens has been achieved, and agricultural productivity has been increased to an unprecedented level. No adequate alternative for the use of pesticides for either of these purposes is expected in the foreseeable future.

The President's Science Advisory Committee pointed out in a 1967 study that, in the developed countries, most of the increase in the use of pesticides has been in

agriculture, whereas, in the developing countries, most of the increase has been due to efforts to control insect vectors of disease.* Moreover, as a result of the greatly reduced incidence of diseases in some developing countries, more food is needed--to feed those saved from disease. These countries must turn to more intensive agriculture to support their growing populations. Modern agricultural productivity depends on coordinated increase in the use of pesticides, fertilizers, machinery, and better crop varieties.

Pesticides that persist in a biologically active form offer certain advantages. If the material breaks down slowly, frequency of application can be reduced and labor costs are correspondingly lowered. If, as a result of its being present in the environment over an extended period, the material accumulates in the tissues of the target species, low initial application rates may well provide effective control. Certain of the persistent compounds have additional advantages over many nonpersistent compounds: they are less hazardous to the persons handling them, and there is less likelihood of immediate harm to nontarget animal and plant species in the treated area.

Farmers sometimes apply more pesticide than the amount needed for controlling pests. The public has come to insist on attractiveness in produce, and this insistence weighs heavily in determining market acceptability. Consequently, extra applications of pesticide are made with the aim of raising the level of control of insects or disease agents from good, or reasonable, to the level of almost perfect. The producer of vegetables for commercial canning may be caught between two tolerance limits--one for pesticide residues and the other for insect parts that are legally defined as "filth." Both tolerances were set indirectly by the decisions of society at large. In some instances,

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*President's Science Advisory Committee, Panel on the World Food Supply, The World Food Problem (Washington, U.S. Government Printing Office, 1967), pp. 138-139.

it may be desirable to reexamine the basis of market quality in the interest of reducing pesticide residues in the environment.

In home gardening and household uses, pesticides may be applied at excessive rates because the user does not know the proper type of pesticide for best results and because he applies them improperly. In doubt as to proper quantity, he may reason that "if some is good, more is better" and thus may apply too much.

Under some conditions, persistent pesticides are the most effective means of controlling pests; under others, they are the only practical means. Many serious public health problems associated with insect vectors of human disease still require the use of persistent pesticides in some countries, either because a suitable short-lived alternative is not available or because the developing countries cannot bear the cost of nonpersistent pesticides, which are usually more expensive than persistent pesticides. Reasonably priced alternative chemicals or nonchemical means may be found in time. Meanwhile, any action to reduce the availability of persistent pesticides needed by developing countries might have serious health consequences in those countries.

There is no satisfactory alternative to persistent pesticides for protecting wood against insects. Long-lived materials may be placed in the soil, or timber may be impregnated to achieve long-term protection, without danger of contaminating the environment.

In the United States, persistent pesticides have some uses for which satisfactory alternatives do not exist. Economic entomologists state that at present, the only chemicals that effectively control certain insects are the persistent ones. The insects to which they refer include certain pests of cotton, corn, wheat, alfalfa, fruit, forest trees, lawns, and turf.

Despite the present need for persistent pesticides, their availability must not inhibit the search for more desirable means of pest control.

MAN AND THE ECOSYSTEM

Any undisturbed land mass is eventually occupied by an assemblage of plants referred to as climax vegetation. This vegetation is stable and self-perpetuating and may consist of many species living together in a small area. When it is destroyed, the area is quickly occupied by plants that have the ability to grow and multiply rapidly. In due course other species invade the area and restoration of the climax begins.

When the human population was small, it was possible for man to depend on climax vegetation and its associated organisms for food, fiber, and shelter. However, it was necessary for man to disturb and to modify some of the earth's climax systems in order to provide sufficient food, fiber, and shelter for the growing human population. Besides being an initial step in establishing present-day civilizations, the development of agriculture was the first stage in destroying the relatively stable ecosystem in which man once lived. To maintain the resultant ecologically unstable situation, he was obliged to initiate many remedial actions, including pest control.

Basic ecological principles dictate that an unstable state will change unless maintained by balancing forces. Monoculture, which is essential today to food production, is ecologically unstable. Continued effort is necessary to maintain it. The effort includes pest control and the use of fertilizers, machines, and selected plant varieties. At present, pests are controlled primarily by use of pesticides, but no matter what method is used, the basic problem remains: monoculture is inherently unstable.

Society could allow farmers to maintain monocultures by any means that they chose, except for the fact that man is a part of the whole ecosystem. Whatever is done in one part of an ecosystem often produces an effect in other parts. Pesticides applied in one area may be transported to remote areas and produce unexpected results. Complete insect control in a cotton field may destroy the bees necessary for pollinating an adjacent alfalfa field. Therefore,

for the good of mankind, it is conceivable that society may wish to put restraints on the use of certain pesticides regardless of economic considerations and crop quality.

PRODUCTION AND USE OF PESTICIDES

The worldwide increase in the use of persistent pesticidal chemicals is cause for concern, and, if trends continue, problems of environmental contamination by such chemicals may become more serious. During the first half of the 10-year period ending June 30, 1967, the use of the principal organochlorine insecticides (DDT, aldrin-dieldrin, toxaphene, etc.) in the United States continued at about the same level. During the last half of the period, a slight decrease occurred. During the whole 10-year period, the use of DDT decreased substantially, but the use of aldrin and dieldrin increased. Undoubtedly, the decrease in the use of the principal organochlorine insecticides from 1962 to 1967, inclusive, resulted from (1) changes in government regulations and agency recommendations concerning use, (2) public pressure to reduce the release of persistent pesticides into the environment, (3) a marked increase in the development of strains of insects resistant to persistent pesticides, and (4) the availability of useful new pesticides of other types.

In the United States, total production of the principal organochlorine insecticides for domestic use and export increased by about one-third in the 10-year period ending June 30, 1966, but the 225 million pounds produced in the last year for which information is available (1966-67) represents a decline from the values of the previous 5 years. During the same 10-year period, the production of DDT increased to a peak value of about 185 million pounds in 1962-63 and decreased to about 60% of this value in 1966-67.

The use of herbicides and fungicides expanded steadily in the last decade of record; the use of herbicides showed a substantial growth. Continued substantial increases are anticipated for herbicides, but little increase is seen

for fungicides. These two groups do not contribute importantly to the problems commonly associated with persistent pesticides.

The total worldwide production of persistent pesticides is not known. This information is necessary if the residues of pesticidal chemicals entering global transport systems and accumulating in the biosphere are to be evaluated and if a realistic appraisal of the effectiveness of residue control measures is to be made.

SIGNIFICANCE OF RESIDUES

Analytical Problems

Residue measurement, as performed in monitoring programs, consists in detecting and measuring minute quantities of pesticidal chemicals. The task requires not only the skillful use of precise, highly sensitive analytical methods but also a proper interpretation of resultant data.

For convenience and speed, pesticide residue chemists generally adopt gas-liquid chromatography (GLC) as their primary analytical technique. Where only GLC is employed, one or more of the following conditions could contribute to erroneous results: (1) failure to utilize adequate confirmatory identification of the pesticide residue, (2) lack of adequate extraction and cleanup procedures, (3) lack of standardized analytical methods, (4) lack of sufficient comparisons to permit the measurement and evaluation of variability between cooperating laboratories and between analyses performed in the same laboratory, (5) presence of artifacts that are interpreted as pesticide residues, and (6) lack of biological materials for controls that are free of pesticide residues.

Health

Understanding of the toxicology of persistent pesticide residues is increasing steadily insofar as warmblooded animals are concerned. However, extrapolation of toxicological data from test animals to man remains uncertain.

Several recent studies that have been conducted with man as the subject do not indicate that the present levels of pesticide residues in man's food and environment produce an adverse effect on his health. These studies have been principally epidemiological.

--Workers involved in the manufacture of DDT, chlordane, dieldrin, heptachlor, and endrin have been the subjects of long-term studies designed to determine whether their exposure had caused any significant alterations in disease frequency or pathology. The evaluations included comprehensive health examinations and monitoring of exposure rates and pesticide residue levels in the workers' tissues. The health of those workers was not found to differ significantly from that of the general population. Yet the pesticide storage levels in the tissues of some of the pesticide workers were 10 to 20 times higher than those found in the general population.

--A nationwide epidemiological study of persistent pesticide residues in several thousand persons has not produced evidence that pesticide residues in the body have an adverse effect on health. A substantial number of the persons involved in this study were exposed to relatively high concentrations of pesticides as a result of occupation or residence; the others were exposed in no unusual way.

Data are available from recent studies concerned with the relation between dosage rates and storage levels. Studies on the storage dynamics of DDT and dieldrin in human volunteers confirmed observations, made in studies of other mammals, that a dosage-storage equilibrium develops.

Many persistent pesticides have been subjected to basic toxicological reevaluations in various test animals.

These studies were conducted to measure chronic effects, including, in most cases, effects on reproduction and carcinogenicity potentials. Studies of aldrin, dieldrin, endrin, heptachlor, heptachlor epoxide, and chlordane in animals have not shown that these chemicals produce significant toxicological effects at dosage levels under 1.0 ppm in the diet, although they produce reversible "adaptive responses" of the liver at a level of 1.0 ppm or higher. These data include results from reproduction studies of rats (in which all six of the above chemicals were used) and dogs (endrin) and from long-term exposure studies of mice, rats, and dogs (endrin and heptachlor); dogs (chlordane); and monkeys (dieldrin).

Increases in liver size induced by these chemicals are accompanied by increased activity of the hepatic microsomal enzymes, and this response increases the tolerance of an animal to the chemical. This adaptive liver response in animals occurs with the administration of any one of more than 200 compounds, including some chemicals naturally present in the environment, many drugs, and various synthetic compounds. Hence, the response in animals is common, and it would be expected to occur in humans also if a sufficient quantity of pesticide were administered.

Steroid hormones are also degraded by the microsomal enzymes of the liver. A widely held view is that increased steroid degradation occurs when persistent organochlorine compounds accumulate in man and other animals. Experimental evidence supports this view, but, as with other toxicological effects, the minimum dosage is apparently above 1.0 ppm of these compounds in the diet.

The ultimate effects, if any, of long-term low-level exposure to persistent pesticides are not understood. Although the existing studies do not indicate the low-level exposure to persistent pesticides is a health hazard for the general public or that higher-level, but subacute exposure is a hazard to persons in certain occupations, additional research on the effects of long-term, low-level exposure is essential.

From this statement of the need for information about possible effects of long-term exposure, it does not necessarily follow that such exposure would be deleterious to health. The point is that definite information is lacking. Both the epidemiological and the mammalian experimentation should be continued, and this experimentation should include studies of the biochemical and physiological effects of prolonged low-level exposure to persistent pesticides.

Food

For as long as persistent organic pesticides have been used, there has been concern about their presence in human food. The primary objective in regulating pesticide use has been to keep residues in food supplies at minimal and safe levels, because food is the principal route by which pesticides normally reach man. Increasing effort has been devoted to inspecting food supplies, and supplies in which residue levels were found to exceed legal tolerances have been condemned. As a result, residues in the food supplies of the United States have been maintained at remarkably low levels during a time of great increase in pesticide use. The Committee believes that, at present, pesticidal chemical residues in food are being maintained at safe levels.

The interaction of inspection and enforcement with research on agricultural practices has resulted in the discontinuance of some uses that were once approved. For example:

--DDT was once used to control flies and other insects on dairy cattle, but this practice was found to result in unacceptable residues in milk.

--Forage grown on fields the year after application of certain organochlorine insecticides sometimes transmits residues to the milk of dairy cattle grazing on the forage.

--Many of the residue tolerances for aldrin, dieldrin, endrin, heptachlor, and DDT were recently reduced or withdrawn. These actions led to discontinuance of some previously recommended uses.

Some pesticides, notably DDT, are so widely distributed that few, if any, food-producing areas are free of their residues. Thus, most foods contain measurable traces of such residues. There is no evidence that these traces are of significance to human health.

Wildlife

Damage to wildlife was recorded soon after persistent pesticides came into general use. Direct mortality of some birds, mammals, and fish followed the application of organochlorine insecticides at heavy rates over large areas. Alarm expressed by various groups, each concerned about the fate of a particular group of animals, has generated strong public reaction to these effects of the use of pesticides.

The period of large-scale, very heavy applications of persistent pesticides appears to be coming to a close in the United States; methods are being refined, application levels are being reduced, and other materials are being substituted. Because of this change in the use of chemicals, some persons expect that serious damage to the biota will be substantially reduced or eliminated.

The Committee concludes that there is substantial evidence of continuing damage in some areas, particularly to fish and birds, by pesticide residues at present environmental levels. There are examples of concentrations in food chains at levels that are lethal to predators. Exposure to pesticides at sublethal levels probably produces more subtle effects, causing changes in the physiology, biochemistry, or behavior of animals that may be harmful to the population as a whole. Certain game fish accumulate pesticidal chemicals by storage in the body and in the fat-rich yolk of egges; there may be no injury to adult fish, but lethal or harmful amounts are acquired by the newly hatched offspring when they absorb the egg yolk. Studies on two continents show that the reproductive success of certain birds of prey is impaired by DDT and its metabolites, which apparently act to reduce eggshell

thickness and thus to increase premature breakage of the eggs.

Certain organochlorine pesticides are hazardous to many species because they are readily absorbed, are stored in body lipids, and are slowly metabolized and excreted. The body lipids are metabolized continually to support the life processes and are continually being replaced. If a predator loses the pesticidal chemical it receives in food as fast as it takes it in, accumulation of the chemical is avoided, whether the loss is by metabolism, excretion, or chemical degradation. If it loses the pesticide at a lesser rate, it accumulates the chemical in its fat. The concentration attained is tolerated without any ill effect, or it causes sublethal injury, or it is lethal. Assuming that a given organism in a food chain is not killed by the pesticide it stores, the next higher predator generally increases the concentration by accumulation. This process repeated several times may result in tissue residue levels several thousand times greater than the level existing in the environment.

The same process occurs in the food supply of man, who is at the top of many food chains. However, it has been possible to stabilize the accumulation of residues in man's food below tolerance levels by controlling the pesticide input for the major food chains.

Where the ecology of pesticide residues is concerned, there are important parts of the biota about which almost nothing is known. Research on the effects of persistent pesticides in the ecosystem is concerned almost entirely with the relatively few forms of life of direct interest to man. These include economic plants, economic insects (both harmful and beneficial), economic fish, shellfish, sport fish, game animals, and birds. Reports of new research may suddenly increase interest in other components of the biota. For example, interest in soil microorganisms increased because of their role in the biochemical degradation of pesticides.

Research on natural populations is a difficult, undeveloped field that is poorly supported at the national level. Methods of field study are imprecise, yet they must be used for populations that fluctuate continually. It is not difficult, for example, to demonstrate the massive lethal effect of a control agent, but it is almost impossible to measure a low-order change in the balance between reproduction and mortality by ordinary field studies. Information on subtle effects can come only from carefully coordinated field and laboratory investigations. Large-scale field experiments will be required to establish whether effects found in the laboratory occur in the field and to allow more general extrapolation from laboratory results to what may be expected in the field. There are no research programs of this magnitude. No public agency is conducting or sponsoring research on the broad ecological effects of pesticides. The Committee believes that such research programs on natural populations should be initiated.

The Environment

Residues of DDT and, occasionally, of other organochlorine insecticides have been recorded in biota in all parts of the world. After being released into an ecosystem, these pesticides are transported about the biosphere by a variety of little-understood mechanisms and are concentrated in the biota. The pesticides about which the greatest concern is felt are those having, to a marked degree, all of the following characteristics: toxicity, persistence, mobility in natural environments, and affinity for the biota.

Wide distribution of DDT and some of the other organochlorine insecticides is inferred from scattered observations. The amounts in environmental stores cannot be compared with the amounts dispersed, because there is too little information on the amounts in the environment. The general presence of DDT and its metabolites in man and other animals is taken by some to imply that large quantities are stored in the biosphere; possibly the observations

reflect only a relatively small circulating store concentrated in the biota. Scattered measurements of DDT in rain and the atmosphere emphasize the need to know what is in the atmosphere. The ready sorption of pesticidal chemicals by silt suggests that the chemicals may be stored in silt deposits in reservoirs, rivers, and estuaries and on the continental shelf, but a few observations support or refute this supposition. Order-of-magnitude estimates of even a few of the important environmental stores of residues would be valuable.

Accumulations are investigated at sites of application in areas where the organochlorine insecticides have been applied heavily. There is increasing evidence that when they are applied to farm fields year after year, the measurable residues in the soil reach a steady state, the amount disappearing each year being about the same as the amount that is applied. In a number of fields in the South, the steady-state level approximates the amount applied in 1 year. Other studies show much greater persistence at the site of application. Nevertheless, continued use of even the long-lived organochlorine insecticides does not result in a constantly increasing accumulation at the site of application. Therefore, the problem of high-level local contamination by pesticidal chemicals is not the same as that presented by arsenical insecticides in orchards.

Disappearance of a pesticide from the site of application may or may not mean that the chemical is being destroyed. Two processes act to reduce the local concentration of pesticide. The first transforms the chemical by biological, chemical, and photochemical degradation. The second transports the chemical to another place.

Organic pesticides are degraded in a number of ways. As a result of work in the last few years, much new information exists on the degradation, metabolism, and fate of persistent pesticides in soil, water, animals, and plants. Some persistent pesticides are subject to photochemical decomposition or are destroyed by nonbiological components of the environment. Some are degraded biologically. Biological degradation occasionally takes place

through enzymatic processes that may result in a complete conversion of organic chemicals to simple, well-known products. In other instances, biological degradation yields organic compounds that are normal constituents of living organisms. Although the return from this research investment has been impressive, vast gaps in knowledge remain. There is relatively little information about the ultimate fate of persistent pesticides in soil or in other parts of any ecosystem, or about the sequence in which the degradation processes take place. For some chemicals of interest, the initial products formed are known and are measurable in monitoring programs; but for these chemicals, the products formed next and the sequence in which they are formed are not known or are known for only a few types of natural habitats. Until these products are identified and their potential biological activities are ascertained, it is impossible to assess meaningfully their toxicity to man or to the biota or their residence times in nature.

Rates of degradation differ with the chemical, the type of degradation, and the place in the environment. In some instances, the parent material or a product generated from it is highly resistant to degradation in all major environments into which it enters. In other instances, the pesticide is long-lived in one habitat but short-lived in another, or it is short-lived in almost any environment. With some chemicals, the degradation is partial; in others, it is extensive. Whether the overall ecological storage of a chemical increases or decreases in a given period depends, of course, on the balance between the rate of input and the rate of degradation during the period.

Like many other chemicals, organochlorine insecticides move about the biosphere. Knowledge concerning this transport is growing, but it is still incomplete with respect to the relative importance of the various mechanisms. Most of the persistent pesticidal chemicals have an extremely low water solubility and a high affinity for colloidal surfaces. These two characteristics explain why the materials are resistant to leaching and move no more than a few inches in the soil profile during a period of several years.

Evidence suggests that general environmental contamination by the chemicals is more likely to occur from wind and water erosion of the soil than through leaching into ground water. One means of transport is the sorption of pesticides to soil particles, especially the fine silt and organic fractions, both at the site of application and in the aquatic environment. Normal processes of erosion transport the soil into streams, rivers, estuaries, and the sea. There are records of pesticides being carried on the ocean winds in association with particles of the talc diluent used in application, and pesticides are probably carried on particles of soil in the same way. Although many chemicals used as pesticides have low vapor pressures, substantial amounts can be transported in the vapor state. Pesticides in the atmosphere are returned to the earth in rain. In addition, a direct air-soil exchange may take place.

Pesticides are carried in the biota, but the relative importance of biological transport is unknown. On the one hand, living things carry relatively high concentrations of residues because of the process of biological concentration; on the other hand, the mass of the biota is very small compared with the total environment. Fish and shellfish may remove certain organochlorine insecticides from their water environment, despite the very low concentrations present, and, if mobile, excrete the chemicals or their metabolites back into the water at a new site. Consumption of one species by a mobile predator species, with consequent transfer of a portion of their body burden of residues, provides an additional avenue of distribution.

Where little or no information is available concerning the transport, accumulation characteristics, and degradation products of a long-lived (persistent) synthetic chemical, it would appear prudent for man to refrain from needlessly releasing the chemical into the biosphere. The crucial questions are: What are the degradation products? How toxic are they? What is their behavior in nature? If a long-lived chemical is released and is later found to be toxic, nothing can be done about the store already dispersed; it must remain in the biosphere until dissipated by the slow processes of degradation and removal.

Release of short-lived material is a different matter. If such a material is released and is later found to be hazardous, the store in the biosphere will be rapidly reduced once the use of the material is discontinued.

Biosphere Stores

The threat of continued accumulation of residues in the environment is responsible for much of the apprehension about the future use of the organochlorine insecticides. Therefore, their rate of degradation to nontoxic compounds of known biological behavior is a crucial factor.

Evidence that degradation destroys residues about as fast as the pesticides are released would be reason to believe that global environmental levels can be controlled by raising or lowering the rate of release. Evidence of continued accretion in the biosphere should force a prompt reappraisal of continued use.

Three kinds of evidence can be examined in deciding whether chemical residues are increasing in the biosphere:

--Evidence gained in studying degradation processes to determine how rapidly chemicals are being destroyed.

--Evidence from monitoring to detect changes in concentration in selected compartments of the biosphere.

--Evidence from measuring residue storage in the total biosphere.

The first two procedures are producing considerable knowledge; however, the third is receiving too little attention.

Chemical degradation of pesticidal chemicals has been investigated extensively in the laboratory. Some studies have been made under selected field conditions, but it is difficult to evaluate the significance of transport away from the study area. Available information indicates that rates of degradation vary with

environmental conditions. Evaluation of the overall rate of disappearance from the biosphere requires quantitative knowledge concerning (1) partitioning of the total residue store and (2) rates of degradation in the principal environmental components. The data now available do not permit estimation of the rate of disappearance of any of the persistent pesticides from the biosphere.

The main objective of the present monitoring programs is to detect changes of pesticide concentration in selected parts of the biosphere. To obtain information on changes, it is necessary to operate a program for several years. The best-organized parts of the present programs relate to pesticide residues in man and his food supply. They cannot furnish reliable indications of changes in the total environment. (See "Monitoring Residues in the Environment," page 19.)

Estimates of the total amounts of residues stored throughout the biosphere would make it possible to establish whether present stores are about the same as the amounts of pesticides that have been manufactured or whether degradation processes have already disposed of most of the pesticides that have been manufactured.

It seems essential at this time to estimate the store of persistent chemicals in the environment and determine whether this store is increasing or decreasing. To be meaningful, the estimate must be on a global scale. Modern sampling design would probably make such an undertaking feasible if international cooperation could be obtained. Presumably, residues are stored primarily in the soil, the water, and the atmosphere; the biota is probably too small to store a significant mass of pesticides.

Metallic Compounds

Several metallic elements are used as pesticides in both the organic and the inorganic form. No matter what form is used, the element persists. Traces of arsenic, lead, and copper occur naturally and are widely

distributed in the biosphere; hence, they are generally found at low levels in crops and soils. Application of pesticides containing any of these elements augments the natural level.

Metallic pesticidal chemicals are highly toxic and are excreted slowly from the body. They were used in the inorganic form in the past, but the current practice is to use organic compounds of these metals. The organic compounds are less toxic on a single-dose basis, but the body metabolizes them to their inorganic form. Precautions concerning degree of exposure and accumulation in the body are the same for the organic derivatives as for the corresponding inorganic compounds.

The use of many of the metallic pesticides is on the wane. However, the increasing use of organic arsenical herbicides presents a growing arsenic-contamination problem.

MONITORING RESIDUES IN THE ENVIRONMENT

The 1963 report of the President's Science Advisory Committee recommended that "current pesticide levels and their trends in man and his environment" be determined and that "a continuing network to monitor residue levels in air, water, soil, man, wildlife, and fish" be developed. In response to these recommendations, several federal agencies set up the National Pesticide Monitoring Program (NPMP), following guidelines provided by the Federal Committee on Pest Control, an interagency body. The agencies that set up NPMP were already engaged in monitoring activities, and they continue to administer the activities that are now identified with NPMP. Some NPMP activities were instituted after NPMP was formed.

In June 1967 the Federal Committee on Pest Control began publishing the Pesticides Monitoring Journal, the purpose of which is to report results of monitoring investigations--both those conducted by agencies associated

with NPMP and those conducted by other agencies. In the first issue, the Journal defined pesticide monitoring as the determination of "the distribution of pesticides in the various elements of the environment and the changes in these levels with time." As NPMP is now conducted, however, the emphasis is on measuring changes in the concentrations of pesticides in selected components of the environment.

Those parts of NPMP that follow pesticides in people are designed to measure changes that occur in selected communities or in tissues obtained from designated hospitals. In contrast, programs related to food emphasize careful objective sampling to determine the average content of a standard diet. Enough dietary components are analyzed separately to permit calculation of residue content for a number of basic diets. In addition, raw produce and meat are randomly sampled. Thus, for food, the program provides not only for measuring changes but also for calculating meaningful average values.

These studies of man and his food have, of course, been set up for good public-health reasons, and statements of objectives are outstandingly clear. If any increase in residues is noted in the samples of man or his food, corrective action generally is taken promptly. However, these studies do not provide data needed for assessing the presence of pesticides in natural environments.

The program for monitoring soils is based on selected sampling of forest, range, and agricultural lands. Most samples of agricultural soils are taken from farms where the history of pesticide use is known. More extensive sampling according to a well-established sampling design is required to provide information on the accumulation of residues in the total soil mass. A plan for expanding soil monitoring to include more general sampling on a statistical basis is being developed.

Pesticides in water are monitored by sampling rivers at selected sites. Changes at these sites are measured, but information on average conditions is lacking. Related samplings are those of shellfish in estuaries, the surface of estuarine sediments, freshwater fish (three species)

taken at a number of points on rivers, and birds (three species). Like the river samplings, these studies are concerned with selected parts of the ecosystem and measure changes; they are not capable of determining the distribution or extent of residues in the various parts of the ecosystem.

Thus, it is seen that the National Pesticide Monitoring Program has two groups of studies and that they differ markedly in their objectives:

--The measurement of residues in human tissues and in food is designed to follow pesticides in man and his food, not to reflect residues in the general environment.

--The sampling of water, shellfish, estuarine sediments, freshwater fish, birds, and (to some extent) soil is designed to furnish index values for measuring changes in the amounts of residue in selected components of the biosphere.

The air-sampling program of NPMP, which is only beginning, should be expanded. Although the technology of air sampling is not well advanced, air sampling must be included in any effort whose aim is to monitor the health-related aspects of man's immediate environment. Further, the absence of quantitative information about transport of pesticides in the atmosphere is a critical deficiency in our understanding of the biosphere circulation of the persistent materials. The Committee believes that an air-sampling network should be established. Primary attention should be given to man's immediate environment, but the network should also monitor the environment generally.

The Committee believes that monitoring programs should include determinations of the concentrations and amounts of pesticide chemicals in the major reservoirs of the biosphere and assessments of the changes in concentration with time. Such information would permit estimation of the amount and rate of change of residues in the biosphere.

The Pesticides Monitoring Journal is a practical response to a real need. Underlying this enterprise is the principle that relevant data should be readily available to the scientific community. Recorded data have lasting value, although early interpretations, being limited by the state of knowledge then existing, sometimes are ephemeral. For this reason, the Committee urges that the various segments of NPMP promptly publish relevant data in the Journal, even when the implications of recorded measurements are obscure.

It should be recognized that monitoring is an important service activity and should not be confused with research. Research is necessary to provide tools for monitoring, but the two activities have different objectives. As soon as information-gathering can be standardized, the monitoring should be separated, administratively and financially, from research. Continuance of monitoring as a function of a research unit can lead to reduced quality in both endeavors.

The Committee believes that the National Pesticide Monitoring Program is at a stage where a thorough examination of objectives and procedures will be beneficial.

CONTROL OF PESTICIDE RESIDUES

Dangers inherent in the use of pesticides have led to adoption of regulations, in the United States and elsewhere, designed to control residues and promote safety. Official regulation must be combined with informed use by applicators. No matter how strict the law may be, its objectives cannot be achieved without understanding and cooperation on the part of applicators.

Legal controls in the United States are partly direct and partly indirect. Direct legal controls are applied to the manufacturer and the shipper of pesticides by federal and state label-registration processes and by inspection for adulteration, misbranding, or inadequate labeling of

the products. Label-registration regulations protect the users of pesticides with regard to quality and effectiveness of the purchased product. They also help to prevent the release into the biosphere of one chemical when the release of another is intended. Certain highly toxic materials (e.g., the rodenticide 1080) are permitted to be used by licensed pest-control operators only. In some states, another mechanism of control is the licensing of applicators.

Agricultural Commodities

A major legal control over pesticide use is the condemnation of agricultural commodities that contain residues in excess of the stated maximum permissible level. Labels on pesticide containers provide, for the guidance of farmers, directions for using the pesticides. If followed, these directions should prevent above-tolerance residues. The directions for use are the result of careful investigations of the effectiveness of a product and of residue levels obtained from stated rates of application. Statements on the label, including directions for use and warnings about harmful effects, are controlled by regulation.

Compliance by farmers is on a voluntary basis, but the fact that they operate under the threat of condemnation of their products if they fail to comply with recommended practices tends to enforce compliance. A precedent has been established for governmental reimbursement for produce found to be contaminated despite the use of approved materials in accordance with recommended practices. Evidence indicates that the objectives of this indirect method of control are being achieved, and that the entry of pesticides into the human diet is being kept at a minimal and safe level. This method of control can be used to reduce further the levels of pesticidal chemicals in food. When new information reveals a formerly unsuspected health hazard, tolerance levels can be lowered, though not below the level of ecological availability.

The Environment

The present indirect method of regulation places emphasis on voluntary compliance by the user and penalizes him only if his own crops carry excessive levels of a pesticide. Despite its limitations, this method is effective locally. However, it seems to lack potential for exercising control over materials that may have an effect in an area remote from the site of application.

If application of a pesticidal chemical results in drift to an area under different ownership and such drift is found to be the cause of loss or condemnation of a crop, losses can be recovered by legal action against the landowner responsible for applying the chemical. This legal principle also extends to protection of fish and other wildlife. Losses of this kind are recoverable by a state in the form of replacement costs. Although fixing individual responsibility is often difficult, the possibility of legal action by either private or public parties moderates the use of pesticides and tends to reduce contamination resulting from drift. In addition, the indirect method is ineffective where pesticides are applied for purposes other than control of crop pests--for example, application of DDT for control of Dutch elm disease or dieldrin for control of the imported fire ant.

In general, present regulations contain inadequate provisions for protecting the environment. That some agency should be responsible for the well-being of the ecosystem seems to be a new idea. Concern for environmental contamination that is not subject to control by any state or federal agency may force a resolution of this question of responsibility.

The Committee believes that attention must be given to the problem of controlling residues in the biosphere. It is doubtful that control of residues in the biosphere can be achieved by the same methods that are effective in food production, because of the impossiblity of fixing individual responsibility for contamination. Regulations to achieve this type of control would be concerned with

benefits in which few citizens have a direct interest. Special efforts, including educational efforts, are needed to explain the benefits and promote public acceptance of the regulations.

Controlling residues in the biosphere is an international problem, and any effective control over the accumulation of long-lived materials in the ecosystems of the world must be through control of use in all nations. Clearly, the United States must do something about its own problems before it can advise other nations to change practices. There exists in our economy a loop of cause and effect that tends to perpetuate the present pattern of materials used. The organochlorine insecticides are of relatively low cost; for many purposes, they are highly effective; from a restricted viewpoint, they are relatively safe. Therefore, they are used in large quantities. Substitute materials having less persistence would probably be used if they were available at equal cost and if they were equally effective. But such substitute materials will not be developed while the present persistent materials are in their advantageous position. Unless there is a change (possibly in the form of regulatory action) by which the persistent materials lose their advantage, they will probably continue in general use.

ALTERNATIVES TO PERSISTENT PESTICIDES

A number of nonchemical approaches to pest control are being developed. These include the growing of resistant crop varieties; cultural and management practices; and control of insects by the use of light traps, attractants, radiation, sterilization, and biological means. Some of these approaches are being used with impressive success.

The nonchemical methods may be used more widely in the future, but speed of adoption and ultimate usefulness are restricted by cost and by lack of applicability to many problems. Often there is an unavoidable delay before control is attainable by biological means. For most purposes, nonchemical methods of control are not expected to supplant

the use of chemicals in the foreseeable future. Hence, some of the pesticidal chemicals are likely to have a place in pest control for many years to come.

Lack of wide-scale adoption of nonchemical control procedures is not the result of any lack of attention devoted to them. They have been under study for many years, and, in recent years, public agencies have committed increasing percentages of their research budgets to the development of nonchemical control. In the same period, financial support for improved chemical control has not kept pace. Paradoxically, resources for studying pesticidal chemicals have decreased in a period in which their use has increased. The Committee believes that the research effort on pesticidal chemicals should be increased and that the present effort on nonchemical methods of pest control should be maintained. A balanced research program should include substantial investments in the search for better nonchemical methods of control, similar commitments for research on new pesticides and improved application of old and new pesticides, and continued study of integrated approaches that include both chemical and nonchemical methods. An integrated approach provides an opportunity for introducing, on a cost-competitive basis, small amounts of new, less persistent materials to replace the low-cost persistent pesticides now in use.

Although environmental contamination can be reduced by substituting a nonpersistent pesticide for a persistent one, this substitution can lead to other problems. Certain nonpersistent pesticidal chemicals are much more hazardous to apply than the chemicals they replace. Others tend to cause immediate injury to pollinating insects or to other animal species of interest to man. Such potential hazards and side effects should be evaluated thoroughly before substitutions are made.

Expanded research on pesticidal chemicals will help in identifying the best one for a given pest-control problem as well as the best method of using it in each situation, thereby providing opportunities for reducing the dissemination of persistent pesticides. To be fully successful, expanded research on pesticides must be accompanied by effective action in three areas: registration of labels,

state and federal recommendations, and education. The educational effort should be directed to insuring that pesticides are used with minimum contamination of the environment.

CONCLUSIONS

1. Persistent pesticides are contributing to the health, food supply, and comfort of mankind, but, in the absence of adequate information on their behavior in nature, prudence dictates that such long-lived chemicals should not be needlessly released into the biosphere.

2. Although persistent pesticides have been replaced in some uses and are replaceable in others, they are at present essential in certain situations.

3. No decrease in the use of pesticides is expected in the foreseeable future. On a world basis, increased use is probable.

4. Although the use of DDT has decreased substantially, there was no important change in the use of other organochlorine insecticides in the United States during the 10-year period ending June 30, 1967.

5. Available evidence does not indicate that present levels of pesticide residues in man's food and environment produce an adverse effect on his health.

6. Registration requirements for persistent pesticides appear to provide adequate safeguards for human health, but continuing attention must be given to accommodating new knowledge and insuring against subtle long-term effects.

7. Residues of certain persistent pesticides in the environment have an adverse effect on some species of wild animals and threaten the existence of others.

8. The availability and low cost of effective persistent pesticides have slowed the development and adoption of alternative methods of control.

9. Work on nonchemical methods as alternatives to persistent pesticides has been emphasized in recent years, and continued support for this work is needed.

10. Inadequate attention and support are being given to developing pesticidal chemicals and to improving techniques for using them.

11. Persistent pesticides are of special concern when their residues possess--in addition to persistence--toxicity, mobility in the environment, and a tendency for storage in the biota.

12. A few organochlorine insecticides and their metabolites have become widely distributed in the biosphere, appearing in the biota at points far from their places of application.

13. The biosphere has a large capacity for storage of persistent pesticides in the soil, water, air, and biota, but little is known concerning amounts of persistent pesticides and of their degradation products that are stored in the biosphere.

14. Knowledge is incomplete concerning the fate and degradation of persistent pesticides in the environment, their behavior in the environment, the toxicity of the degradation products, and the interaction of these products with other chemicals.

15. Present methods of regulating the marketing and use of persistent pesticides appear to accomplish the objectives of providing the user with a properly labeled product and holding the amounts of residue in man and his food at a low level. However, they do not appear to insure the prevention of environmental contamination.

16. Public demand for attractiveness in fruit and vegetables, and statutory limits on the presence of insect parts in processed foods, have invited excessive use of pesticides.

17. The National Pesticide Monitoring Program provides adequate information about residues in man and his food, but it does not provide adequate information about the environment generally, because it can detect changes in residues only in selected parts of the biosphere.

18. Contamination of the biosphere resulting from the use of persistent pesticides is an international problem. Changes in techniques for using these pesticides and the substitution of alternatives here and abroad are questions of immediate concern to all mankind.

RECOMMENDATIONS

The Committee recommends--

1. That further and more effective steps be taken to reduce the needless or inadvertent release of persistent pesticides into the environment.

2. That, in the public interest, action be increased at international, national, and local levels to minimize environmental contamination where the use of persistent pesticides remains advisable.

3. That studies of the possible long-term effects of low levels of persistent pesticides on man and other mammals be intensified.

4. That efforts to assess the behavior of persistent pesticides and their ecological implications in the environment be expanded and intensified.

5. That public funds for research on chemical methods of pest control be increased without sacrifice of effort on nonchemical methods.

6. That the present system of regulation, inspection, and monitoring to protect man and his food supply from pesticide contamination be continued.

7. That the objectives and procedures of the National Pesticide Monitoring Program be reviewed and that the feasibility of obtaining data on quantities of persistent pesticides in the biosphere be studied.

Appendix

PERSONS INTERVIEWED BY THE COMMITTEE ON PERSISTENT PESTICIDES

W. J. Aunan, American Meat Institute
Jack Barnes, Cooperative State Research Service, U.S. Department of Agriculture
Harold L. Barrows, Agricultural Research Service, U.S. Department of Agriculture
William F. Barthel, Chief, Toxicology Laboratory, National Communicable Disease Center, U.S. Department of Health, Education, and Welfare
George A. Bevier, Aedes aegypti Program, National Communicable Disease Center, U.S. Department of Health, Education, and Welfare
W. Frank Blair, Ecological Society of America
Parke Brinkley, President, National Agricultural Chemicals Association
G. S. Buck, Jr., National Cotton Council
John L. Buckley, U.S. Department of the Interior (now with Office of Science and Technology)
William Buren, Grants Office, National Communicable Disease Center, U.S. Department of Health, Education, and Welfare
Philip A. Butler, Gulf Breeze Biological Laboratory, Bureau of Commercial Fisheries, U.S. Department of the Interior
D. A. Chant, Ecological Society of America
Roland Clement, National Audubon Society
Robert Courter, Pesticide Program, National Communicable Disease Center, U.S. Department of Health, Education, and Welfare
E. A. Crosby, Agricultural Research Institute, Pesticide Committee, and National Canners Association
Fred H. Dale, Bureau of Sport Fisheries and Wildlife, U.S. Department of the Interior
Edward S. Deevey, Ecological Society of America
William Durham, Chief, Pesticide Research Laboratory, National Communicable Disease Center, U.S. Department of Health, Education, and Welfare

Walter H. Durum, Water Resources Division, Geological Survey, U.S. Department of the Interior
Eugene H. Dustman, Bureau of Sport Fisheries and Wildlife, U.S. Department of the Interior
Walter W. Dykstra, Bureau of Sport Fisheries and Wildlife, U.S. Department of the Interior
R. P. Farrow, National Canners Association
John Ford, Hercules Incorporated
Milton J. Foter, Pesticide Program, National Communicable Disease Center, U.S. Department of Health, Education, and Welfare
D. Lee Fowler, Agricultural Stabilization and Conservation Service, U.S. Department of Agriculture
Leo R. Gardner, Chevron Chemical Company (arsenic)
Ben Gladdings, California Department of Fish and Game
Arthur Gohlke, Tennessee Corporation (copper)
S. A. Hall, Agricultural Research Service, U.S. Department of Agriculture
Robert E. Hamman, Geigy Agricultural Chemicals
J. Ralph Hansen, Hercules Incorporated
T. H. Harris, U.S. Department of Health, Education, and Welfare
Wayland J. Hayes, Chief Toxicologist, National Communicable Disease Center, U.S. Department of Health, Education, and Welfare
Harry W. Hayes, Agricultural Research Service, U.S. Department of Agriculture
Patrick Healy, National Milk Producers Association
Lyman S. Henderson, Agricultural Research Service, U.S. Department of Agriculture
Joseph J. Hickey, Ecological Society of America
John Hillis, California Department of Agriculture
Ralph E. Hodgson, Agricultural Research Service, U.S. Department of Agriculture
C. H. Hoffman, Agricultural Research Service, U.S. Department of Agriculture
Eldridge Hunt, California Department of Fish and Game
Phil C. Kearney, Agricultural Research Service, U.S. Department of Agriculture
E. F. Knipling, Agricultural Research Service, U.S. Department of Agriculture

O. F. Kolari, American Meat Institute
Sheldon M. Lambert, Shell Development Company (soil-chemical interactions)
L. C. LaMotte, Jr., Community Studies, National Communicable Disease Center, U.S. Department of Health, Education, and Welfare
Kendrick Lee, Bureau of the Budget (Aedes aegypti Program)
Allan B. Lemmon, California Department of Agriculture
L. A. Liljedahl, Agricultural Research Service, U.S. Department of Agriculture
Bernard H. Lorant, Velsicol Chemical Corporation
James H. McDermott, Federal Water Pollution Control Administration, U.S. Department of the Interior
Lewis E. Mitchell, Shell Chemical Company
Donald Mount, National Water Quality Laboratory, U.S. Department of the Interior
William Murray, Federal Committee on Pest Control
Joseph Noone, National Agricultural Chemicals Association
Don Pierce, Forest Service, U.S. Department of Agriculture
P. B. Polen, Velsicol Chemical Corporation
R. D. Radeleff, Agricultural Research Service, U.S. Department of Agriculture
L. L. Ramsay, Food and Drug Administration, U.S. Department of Health, Education, and Welfare
George Reich, Community Studies, National Communicable Disease Center, U.S. Department of Health, Education, and Welfare
William Reichel, Bureau of Sport Fisheries and Wildlife, U.S. Department of the Interior
Robert L. Rudd, Ecological Society of America
Paul F. Sand, Agricultural Research Service, U.S. Department of Agriculture
Eldon Savage, State Services Section, National Communicable Disease Center, U.S. Department of Health, Education, and Welfare
K. L. Schultz, Velsicol Chemical Corporation
David J. Sencer, Director, National Communicable Disease Center, U.S. Department of Health, Education, and Welfare
W. C. Shaw, Agricultural Research Service, U.S. Department of Agriculture

H. H. Shepherd, Agricultural Stabilization and Conservation Service, U.S. Department of Agriculture
S. W. Simmons, Chief, Pesticide Program, National Communicable Disease Center, U.S. Department of Health, Education, and Welfare
M. Joe Sloan, Shell Chemical Company
Edward H. Smith, Committee on Agricultural Land Use and Wildlife Resources, National Academy of Sciences-National Research Council
Donald A. Spencer, National Agricultural Chemicals Association
Robert Stevens, Forest Service, U.S. Department of Agriculture
Lucille Stickel, Bureau of Sport Fisheries and Wildlife, U.S. Department of the Interior
William Stickel, Bureau of Sport Fisheries and Wildlife, U.S. Department of the Interior
Edward Swift, Agricultural Extension, University of California, Berkeley
Ely M. Swisher, Rohm and Haas Company
Alan W. Taylor, Agricultural Research Service, U.S. Department of Agriculture
Edward J. Thacker, Agricultural Research Service, U.S. Department of Agriculture
William Upholt, Federal Committee on Pest Control
Charles R. Walker, Bureau of Sport Fisheries and Wildlife, U.S. Department of the Interior
George M. Woodwell, Ecological Society of America
Anne Yobs, Pesticide Surveillance Unit, National Communicable Disease Center, U.S. Department of Health, Education,and Welfare